



January 2003

## LM19

### 2.4V, 10μA, TO-92 Temperature Sensor

#### General Description

The LM19 is a precision analog output CMOS integrated-circuit temperature sensor that operates over a  $-55^{\circ}\text{C}$  to  $+130^{\circ}\text{C}$  temperature range. The power supply operating range is  $+2.4\text{ V}$  to  $+5.5\text{ V}$ . The transfer function of LM19 is predominately linear, yet has a slight predictable parabolic curvature. The accuracy of the LM19 when specified to a parabolic transfer function is  $\pm 2.5^{\circ}\text{C}$  at an ambient temperature of  $+30^{\circ}\text{C}$ . The temperature error increases linearly and reaches a maximum of  $\pm 3.8^{\circ}\text{C}$  at the temperature range extremes. The temperature range is affected by the power supply voltage. At a power supply voltage of  $2.7\text{ V}$  to  $5.5\text{ V}$  the temperature range extremes are  $+130^{\circ}\text{C}$  and  $-55^{\circ}\text{C}$ . Decreasing the power supply voltage to  $2.4\text{ V}$  changes the negative extreme to  $-30^{\circ}\text{C}$ , while the positive remains at  $+130^{\circ}\text{C}$ .

The LM19's quiescent current is less than  $10\text{ }\mu\text{A}$ . Therefore, self-heating is less than  $0.02^{\circ}\text{C}$  in still air. Shutdown capability for the LM19 is intrinsic because its inherent low power consumption allows it to be powered directly from the output of many logic gates or does not necessitate shutdown at all.

#### Applications

- Cellular Phones
- Computers
- Power Supply Modules

- Battery Management
- FAX Machines
- Printers
- HVAC
- Disk Drives
- Appliances

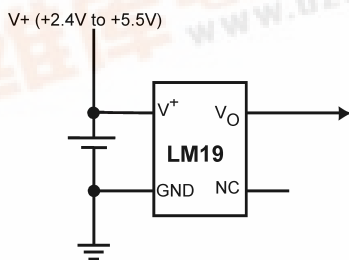
#### Features

- Rated for full  $-55^{\circ}\text{C}$  to  $+130^{\circ}\text{C}$  range
- Available in a TO-92 package
- Predictable curvature error
- Suitable for remote applications

#### Key Specifications

- |  |   |
|--|---|
| ■ Accuracy at $+30^{\circ}\text{C}$                          | $\pm 2.5^{\circ}\text{C}$ (max)                       |
| ■ Accuracy at $+130^{\circ}\text{C}$ & $-55^{\circ}\text{C}$ | $\pm 3.5$ to $\pm 3.8^{\circ}\text{C}$ (max)          |
| ■ Power Supply Voltage Range                                 | $+2.4\text{ V}$ to $+5.5\text{ V}$                    |
| ■ Current Drain  | $10\text{ }\mu\text{A}$ (max)                         |
| ■ Nonlinearity   | $\pm 0.4\%$ (typ)                                     |
| ■ Output Impedance   | $160\text{ }\Omega$ (max)                             |
| ■ Load Regulation  | $0\text{ }\mu\text{A} < I_L < +16\text{ }\mu\text{A}$ |
|  | $-2.5\text{ mV}$ (max)                                |

#### Typical Application



$$V_O = (-3.88 \times 10^{-6} T^2) + (-1.15 \times 10^{-2} T) + 1.8639$$

or

$$T = -1481.96 + \sqrt{2.1962 \times 10^6 + \frac{(1.8639 - V_O)}{3.88 \times 10^{-6}}}$$

where:

T is temperature, and  $V_O$  is the measured output voltage of the LM19.

Output Voltage vs Temperature

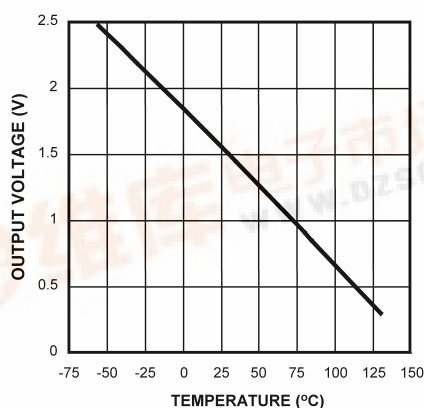


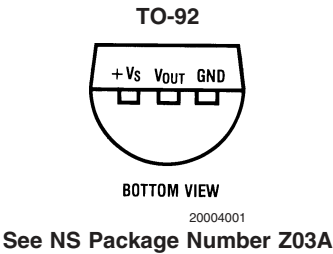
FIGURE 1. Full-Range Celsius (Centigrade) Temperature Sensor ( $-55^{\circ}\text{C}$  to  $+130^{\circ}\text{C}$ ) Operating from a Single Li-Ion Battery Cell

LM19 2.4V, 10μA, TO-92 Temperature Sensor

Typical Application (Continued)

Temperature (T)	Typical V <sub>O</sub>
+130°C	+303 mV
+100°C	+675 mV
+80°C	+919 mV
+30°C	+1515 mV
+25°C	+1574 mV
0°C	+1863.9 mV
−30°C	+2205 mV
−40°C	+2318 mV
−55°C	+2485 mV

Connection Diagram



Ordering Information

Order Number	Temperature Accuracy	Temperature Range	NS Package Number	Device Marking	Transport Media
LM19CIZ	±3.8°C	−55°C to +130°C	Z03A	LM19CIZ	Bulk

**Absolute Maximum Ratings** (Note 1)

Supply Voltage	+6.5V to -0.2V
Output Voltage	(V <sup>+</sup> + 0.6 V) to -0.6 V
Output Current	10 mA
Input Current at any pin (Note 2)	5 mA
Storage Temperature	-65°C to +150°C
Maximum Junction Temperature (T <sub>JMAX</sub> )	+150°C
ESD Susceptibility (Note 3) :	
Human Body Model	2500 V
Machine Model	250 V

Lead Temperature

TO-92 Package

Soldering (3 seconds dwell)

+240°C

**Operating Ratings**(Note 1)

Specified Temperature Range:	<b>T<sub>MIN</sub> ≤ T<sub>A</sub> ≤ T<sub>MAX</sub></b>
2.4 V ≤ V <sup>+</sup> ≤ 2.7 V	-30°C ≤ T <sub>A</sub> ≤ +130°C
2.7 V ≤ V <sup>+</sup> ≤ 5.5 V	-55°C ≤ T <sub>A</sub> ≤ +130°C
Supply Voltage Range (V <sup>+</sup> )	+2.4 V to +5.5 V
Thermal Resistance, θ <sub>JA</sub> (Note 4)	
TO-92	150°C/W

**Electrical Characteristics**

Unless otherwise noted, these specifications apply for V<sup>+</sup> = +2.7 V<sub>DC</sub>. **Boldface limits apply for T<sub>A</sub> = T<sub>J</sub> = T<sub>MIN</sub> to T<sub>MAX</sub>** ; all other limits T<sub>A</sub> = T<sub>J</sub> = 25°C; Unless otherwise noted.

Parameter	Conditions	Typical (Note 5)	LM19C	Units (Limit)
			Limits (Note 6)	
Temperature to Voltage Error V <sub>O</sub> = (-3.88x10 <sup>-6</sup> xT <sup>2</sup> ) + (-1.15x10 <sup>-2</sup> xT) + 1.8639V (Note 7)	T <sub>A</sub> = +25°C to +30°C		±2.5	°C (max)
	T <sub>A</sub> = +130°C		<b>±3.5</b>	°C (max)
	T <sub>A</sub> = +125°C		<b>±3.5</b>	°C (max)
	T <sub>A</sub> = +100°C		<b>±3.2</b>	°C (max)
	T <sub>A</sub> = +85°C		<b>±3.1</b>	°C (max)
	T <sub>A</sub> = +80°C		<b>±3.0</b>	°C (max)
	T <sub>A</sub> = 0°C		<b>±2.9</b>	°C (max)
	T <sub>A</sub> = -30°C		<b>±3.3</b>	°C (min)
	T <sub>A</sub> = -40°C		<b>±3.5</b>	°C (max)
	T <sub>A</sub> = -55°C		<b>±3.8</b>	°C (max)
Output Voltage at 0°C		+1.8639		V
Variance from Curve		±1.0		°C
Non-Linearity (Note 8)	-20°C ≤ T <sub>A</sub> ≤ +80°C	±0.4		%
Sensor Gain (Temperature Sensitivity or Average Slope) to equation: V <sub>O</sub> = -11.77 mV/°C x T + 1.860V	-30°C ≤ T <sub>A</sub> ≤ +100°C	-11.77	<b>-11.0</b> <b>-12.6</b>	mV/°C (min) mV/°C (max)
Output Impedance	0 μA ≤ I <sub>L</sub> ≤ +16 μA (Notes 10, 11)		<b>160</b>	Ω (max)
Load Regulation(Note 9)	0 μA ≤ I <sub>L</sub> ≤ +16 μA (Notes 10, 11)		<b>-2.5</b>	mV (max)
Line Regulation	+2.4 V ≤ V <sup>+</sup> ≤ +5.0V		<b>+3.7</b>	mV/V (max)
	+5.0 V ≤ V <sup>+</sup> ≤ +5.5 V		<b>+11</b>	mV (max)
Quiescent Current	+2.4 V ≤ V <sup>+</sup> ≤ +5.0V	4.5	7	μA (max)
	+5.0V ≤ V <sup>+</sup> ≤ +5.5V	4.5	9	μA (max)
	+2.4 V ≤ V <sup>+</sup> ≤ +5.0V	4.5	<b>10</b>	μA (max)
Change of Quiescent Current	+2.4 V ≤ V <sup>+</sup> ≤ +5.5V	+0.7		μA
Temperature Coefficient of Quiescent Current		-11		nA/°C
Shutdown Current	V <sup>+</sup> ≤ +0.8 V	0.02		μA

## Electrical Characteristics (Continued)

**Note 1:** Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits. For guaranteed specifications and test conditions, see the Electrical Characteristics. The guaranteed specifications apply only for the test conditions listed. Some performance characteristics may degrade when the device is not operated under the listed test conditions.

**Note 2:** When the input voltage ( $V_I$ ) at any pin exceeds power supplies ( $V_I < \text{GND}$  or  $V_I > V^+$ ), the current at that pin should be limited to 5 mA.

**Note 3:** The human body model is a 100 pF capacitor discharged through a 1.5 k $\Omega$  resistor into each pin. The machine model is a 200 pF capacitor discharged directly into each pin.

**Note 4:** The junction to ambient thermal resistance ( $\theta_{JA}$ ) is specified without a heat sink in still air.

**Note 5:** Typicals are at  $T_J = T_A = 25^\circ\text{C}$  and represent most likely parametric norm.

**Note 6:** Limits are guaranteed to National's AOQL (Average Outgoing Quality Level).

**Note 7:** Accuracy is defined as the error between the measured and calculated output voltage at the specified conditions of voltage, current, and temperature (expressed in  $^\circ\text{C}$ ).

**Note 8:** Non-Linearity is defined as the deviation of the calculated output-voltage-versus-temperature curve from the best-fit straight line, over the temperature range specified.

**Note 9:** Regulation is measured at constant junction temperature, using pulse testing with a low duty cycle. Changes in output due to heating effects can be computed by multiplying the internal dissipation by the thermal resistance.

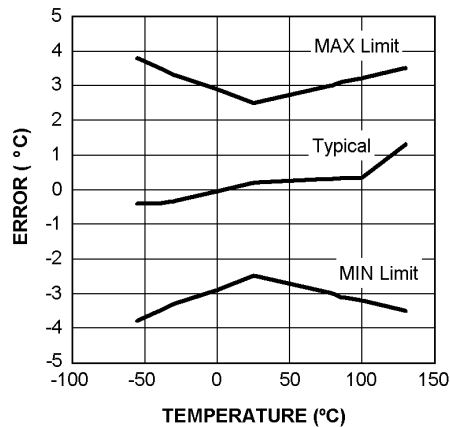
**Note 10:** Negative currents are flowing into the LM19. Positive currents are flowing out of the LM19. Using this convention the LM19 can at most sink  $-1\ \mu\text{A}$  and source  $+16\ \mu\text{A}$ .

**Note 11:** Load regulation or output impedance specifications apply over the supply voltage range of  $+2.4\text{V}$  to  $+5.5\text{V}$ .

**Note 12:** Line regulation is calculated by subtracting the output voltage at the highest supply input voltage from the output voltage at the lowest supply input voltage.

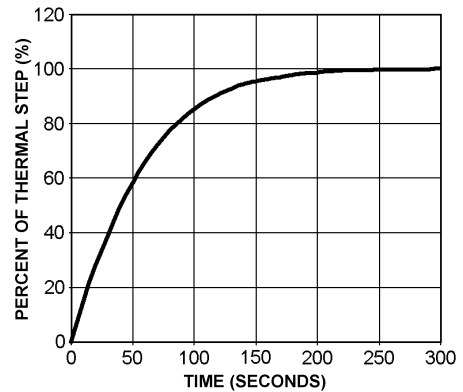
## Typical Performance Characteristics

Temperature Error vs. Temperature



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Thermal Response in Still Air



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### 1.0 LM19 Transfer Function

The LM19's transfer function can be described in different ways with varying levels of precision. A simple linear transfer function, with good accuracy near  $25^\circ\text{C}$ , is

$$V_O = -11.69\ \text{mV}/^\circ\text{C} \times T + 1.8663\ \text{V}$$

Over the full operating temperature range of  $-55^\circ\text{C}$  to  $+130^\circ\text{C}$ , best accuracy can be obtained by using the parabolic transfer function

$$V_O = (-3.88 \times 10^{-6} \times T^2) + (-1.15 \times 10^{-2} \times T) + 1.8639$$

solving for T:

$$T = -1481.96 + \sqrt{2.1962 \times 10^6 + \frac{(1.8639 - V_O)}{3.88 \times 10^{-6}}}$$

A linear transfer function can be used over a limited temperature range by calculating a slope and offset that give best results over that range. A linear transfer function can be calculated from the parabolic transfer function of the LM19. The slope of the linear transfer function can be calculated using the following equation:

$$m = -7.76 \times 10^{-6} \times T - 0.0115,$$

where T is the middle of the temperature range of interest and m is in  $\text{V}/^\circ\text{C}$ . For example for the temperature range of  $T_{\min} = -30$  to  $T_{\max} = +100^\circ\text{C}$ :

$$T = 35^\circ\text{C}$$

and

$$m = -11.77\ \text{mV}/^\circ\text{C}$$

The offset of the linear transfer function can be calculated using the following equation:

$$b = (V_{OP}(T_{\max}) + V_{OP}(T) + m \times (T_{\max} + T))/2$$

,

where:

- $V_{OP}(T_{\max})$  is the calculated output voltage at  $T_{\max}$  using the parabolic transfer function for  $V_O$
- $V_{OP}(T)$  is the calculated output voltage at T using the parabolic transfer function for  $V_O$ .

Using this procedure the best fit linear transfer function for many popular temperature ranges was calculated in Figure 2. As shown in Figure 2 the error that is introduced by the linear transfer function increases with wider temperature ranges.

## 1.0 LM19 Transfer Function (Continued)

Temperature Range		Linear Equation $V_O =$	Maximum Deviation of Linear Equation from Parabolic Equation ( $^{\circ}\text{C}$ )
$T_{\min}$ ( $^{\circ}\text{C}$ )	$T_{\max}$ ( $^{\circ}\text{C}$ )		
-55	+130	$-11.79 \text{ mV}/^{\circ}\text{C} \times T + 1.8528 \text{ V}$	$\pm 1.41$
-40	+110	$-11.77 \text{ mV}/^{\circ}\text{C} \times T + 1.8577 \text{ V}$	$\pm 0.93$
-30	+100	$-11.77 \text{ mV}/^{\circ}\text{C} \times T + 1.8605 \text{ V}$	$\pm 0.70$
-40	+85	$-11.67 \text{ mV}/^{\circ}\text{C} \times T + 1.8583 \text{ V}$	$\pm 0.65$
-10	+65	$-11.71 \text{ mV}/^{\circ}\text{C} \times T + 1.8641 \text{ V}$	$\pm 0.23$
+35	+45	$-11.81 \text{ mV}/^{\circ}\text{C} \times T + 1.8701 \text{ V}$	$\pm 0.004$
+20	+30	$-11.69 \text{ mV}/^{\circ}\text{C} \times T + 1.8663 \text{ V}$	$\pm 0.004$

FIGURE 2. First Order Equations Optimized For Different Temperature Ranges.

## 2.0 Mounting

The LM19 can be applied easily in the same way as other integrated-circuit temperature sensors. It can be glued or cemented to a surface. The temperature that the LM19 is sensing will be within about  $\pm 0.02^{\circ}\text{C}$  of the surface temperature to which the LM19's leads are attached.

This presumes that the ambient air temperature is almost the same as the surface temperature; if the air temperature were much higher or lower than the surface temperature, the actual temperature measured would be at an intermediate temperature between the surface temperature and the air temperature.

To ensure good thermal conductivity the backside of the LM19 die is directly attached to the GND pin. The temperatures of the lands and traces to the other leads of the LM19 will also affect the temperature that is being sensed.

Alternatively, the LM19 can be mounted inside a sealed-end metal tube, and can then be dipped into a bath or screwed into a threaded hole in a tank. As with any IC, the LM19 and accompanying wiring and circuits must be kept insulated and dry, to avoid leakage and corrosion. This is especially true if the circuit may operate at cold temperatures where condensation can occur. Printed-circuit coatings and varnishes such as Humiseal and epoxy paints or dips are often used to ensure that moisture cannot corrode the LM19 or its connections.

The thermal resistance junction to ambient ( $\theta_{JA}$ ) is the parameter used to calculate the rise of a device junction temperature due to its power dissipation. For the LM19 the equation used to calculate the rise in the die temperature is as follows:

$$T_J = T_A + \theta_{JA} [(V^+ I_Q) + (V^+ - V_O) I_L]$$

where  $I_Q$  is the quiescent current and  $I_L$  is the load current on the output. Since the LM19's junction temperature is the actual temperature being measured care should be taken to minimize the load current that the LM19 is required to drive.

The tables shown in Figure 3 summarize the rise in die temperature of the LM19 without any loading, and the thermal resistance for different conditions.

	TO-92 no heat sink		TO-92 small heat fin	
	$\theta_{JA}$ ( $^{\circ}\text{C}/\text{W}$ )	$T_J - T_A$ ( $^{\circ}\text{C}$ )	$\theta_{JA}$ ( $^{\circ}\text{C}/\text{W}$ )	$T_J - T_A$ ( $^{\circ}\text{C}$ )
Still air	150	TBD	TBD	TBD
Moving air	TBD	TBD	TBD	TBD

FIGURE 3. Temperature Rise of LM19 Due to Self-Heating and Thermal Resistance ( $\theta_{JA}$ )

## 3.0 Capacitive Loads

The LM19 handles capacitive loading well. Without any precautions, the LM19 can drive any capacitive load less than 300 pF as shown in Figure 4. Over the specified temperature range the LM19 has a maximum output impedance of 160  $\Omega$ . In an extremely noisy environment it may be necessary to add some filtering to minimize noise pickup. It is recommended that 0.1  $\mu\text{F}$  be added from  $V^+$  to GND to bypass the power supply voltage, as shown in Figure 5. In a noisy environment it may even be necessary to add a capacitor from the output to ground with a series resistor as shown in Figure 5. A 1  $\mu\text{F}$  output capacitor with the 160  $\Omega$  maximum output impedance and a 200  $\Omega$  series resistor will form a 442 Hz lowpass filter. Since the thermal time constant of the LM19 is much slower, the overall response time of the LM19 will not be significantly affected.

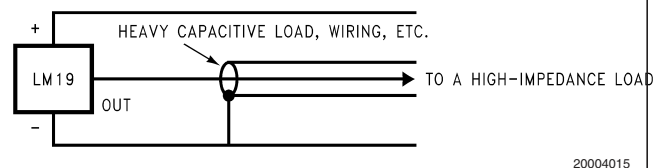
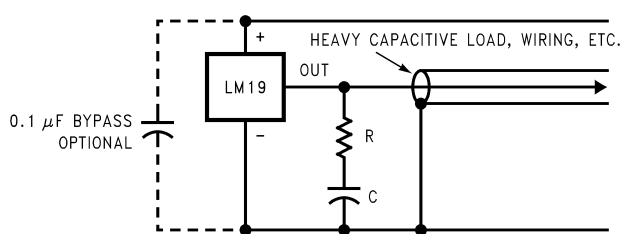


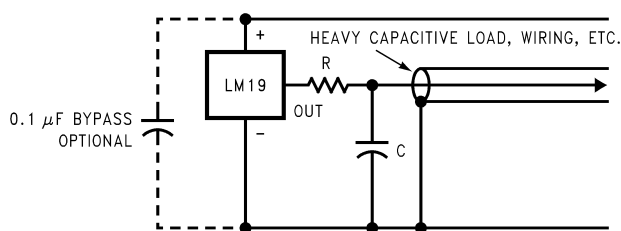
FIGURE 4. LM19 No Decoupling Required for Capacitive Loads Less than 300 pF.

### 3.0 Capacitive Loads (Continued)



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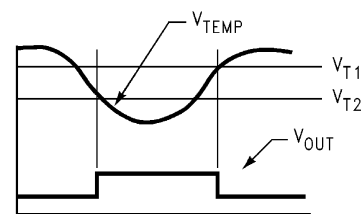
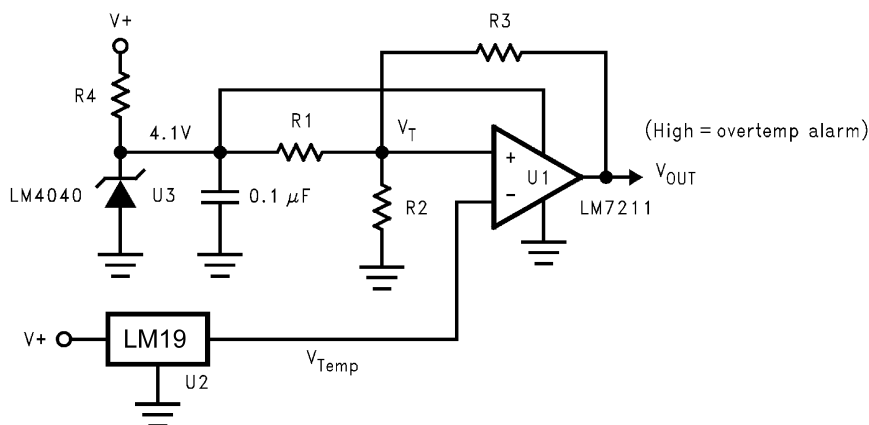
R ( $\Omega$ )	C ( $\mu$ F)
200	1
470	0.1
680	0.01
1 k	0.001



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**FIGURE 5. LM19 with Filter for Noisy Environment and Capacitive Loading greater than 300 pF. Either placement of resistor as shown above is just as effective.**

## 4.0 Applications Circuits

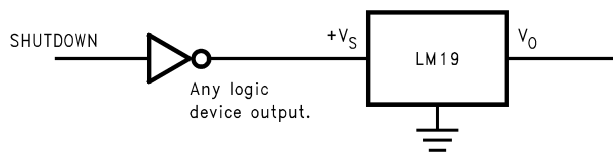


$$V_{T1} = \frac{(4.1)R2}{R1 + R2||R3}$$

$$V_{T2} = \frac{(4.1)R2}{R2 + R1||R3}$$

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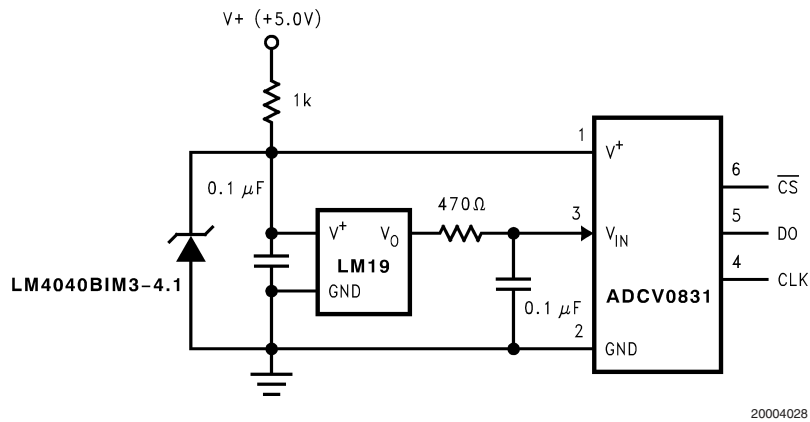
### FIGURE 6. Centigrade Thermostat



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### FIGURE 7. Conserving Power Dissipation with Shutdown

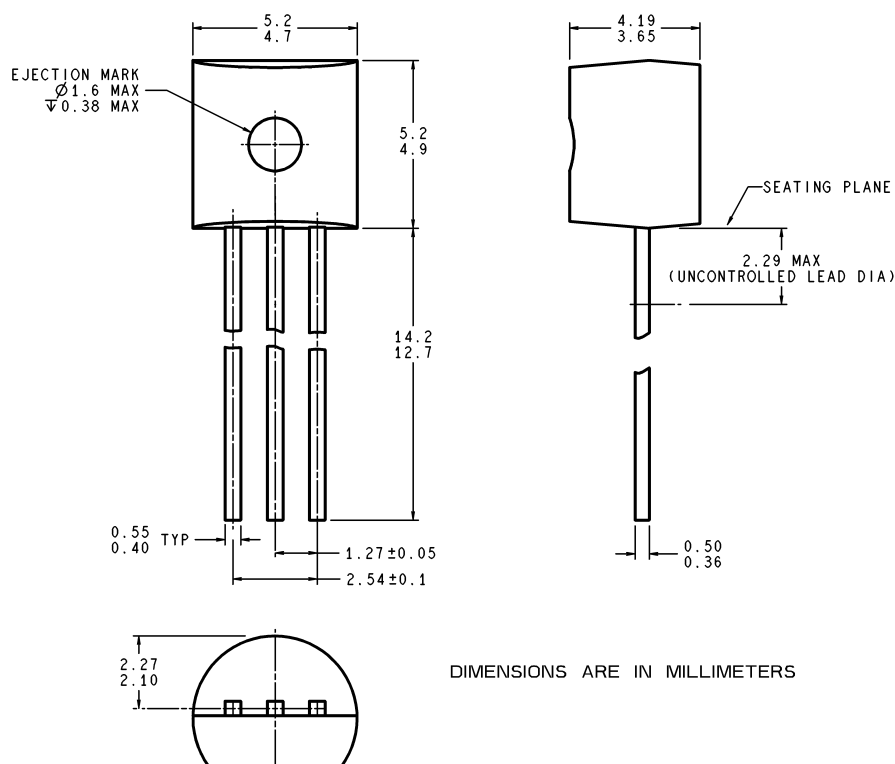
## 4.0 Applications Circuits (Continued)



Most CMOS ADCs found in ASICs have a sampled data comparator input structure that is notorious for causing grief to analog output devices such as the LM19 and many op amps. The cause of this grief is the requirement of instantaneous charge of the input sampling capacitor in the ADC. This requirement is easily accommodated by the addition of a capacitor. Since not all ADCs have identical input stages, the charge requirements will vary necessitating a different value of compensating capacitor. This ADC is shown as an example only. If a digital output temperature is required please refer to devices such as the LM74.

**FIGURE 8. Suggested Connection to a Sampling Analog to Digital Converter Input Stage**

## Physical Dimensions inches (millimeters) unless otherwise noted



Z03A (Rev 6)

**3-Lead TO-92 Plastic Package (Z)**  
**Order Number LM19CIZ**  
**NS Package Number Z03A**

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